The Age of Science 1900-1950

In the first half of this century man has vastly enlarged his understanding and control of nature. An introduction to the 10 articles in this issue

by J. R. Oppenheimer

THE SURFACE OF THE EARTH is photographed from a height of 18 miles by a camera in an Aerobee rocket. Man's deepest penetration of space by rocket: 250 miles by a two-step machine on February 24, 1949.

ONE EVENING more than 20 years ago Dirac, who was in Göttingen working on his quantum theory of radiation, took me to task with characteristic gentleness. "I understand," he said, "that you are writing poetry as well as working at physics. I do not see how you can do both. In science one tries to say something that no one knew before in a way that everyone can understand. Whereas in poetry . . ."

The 10 reports here, to which these words may serve as introduction, do indeed attest that science says things that no one knew before in a way we can all understand. They are reports, each written by a man eminent in his science, of what has happened in that science during the last half-century. They are diverse in style and in substance, reflecting the great diversity of the several sciences and the healthy and heartening diversity of the authors. Yet they all tell heroic stories. They all tell of a period of unparalleled advance of understanding, of new experience, new insight and new mastery. Indeed, for some of the sciences—for biochemistry, for physics, for genetics—the half-century now closing has been a time of splendor: of great men and great discoveries, of a real revolution in our knowledge of the world. For all it has been a time of extraordinary vitality and progress, extending and enriching what we know about the world, and unearthing, for every question answered, a host of new questions. Few of the authors, schooled by the surprises and wonders unfolded in the history of the last 50 years, hazard much of a preview of the history of the half-century to come; yet all speak with confidence of a future that will be worthy of a great past.

For truly science is a prototype of human progress. Its advances in experience and technique, in knowledge and understanding—these are never undone. Even its errors and its byways turn out, usually before many years have passed, to be an enrichment and not a perversion of knowledge. In its application to practice, in extending the resources available to mankind, as well as in its ever-growing contributions to human understanding, it has sustained and nourished the very ideal of the progress of human civilization.

All the reports are pervaded, though necessarily and properly with varying emphasis, by this sense of the dual role of science. The purpose and the fruits of science are discovery and understanding. Yet equally, though in a quite different sense, its purpose and its fruits are a vast extension of human resources, of man's power to control and alter the environment in which he lives, works, suffers and perishes. Some of the authors, perhaps notably Pauling, tend to speak of the future advances in terms of the triumphs of practice that further understanding will make possible. Kroeber speaks only most casually of practical benefits. Born, writing with the caution that experience has forced upon the physicists, refers briefly to the "formidable issues" that the advances in that science have raised. But perhaps the wisest, because most frankly paradoxical, words are those that conclude Meyerhof's brilliant report:

"Biochemistry has an important bearing on the progress of medicine. But because of this, it must remain a pure science, whose initiates are inspired by a craving for understanding and by nothing else."

With that surely most scientists will agree. We hope also for agreement and understanding from an increasing number of men who are not scientists, but who are nevertheless concerned that advances in science make the greatest possible contribution to human welfare.

Oppenheimer

YET AT THIS hour in history one cannot read these 10 reports, which constitute so substantial an account of heroic human achievement and so persuasive an example of the progress of civilization, without being sensible of a darker shadow, quite outside this serene and active workshop of the human spirit, and yet somehow touching it. Scientific progress, which has so profoundly altered both the material and the spiritual quality of our civilization, is not the sole root of its present grave crisis. But few men can be doubtful of its decisive part. Hand in hand, the growth of science and of the practical arts has produced, is increasingly producing, an unparalleled revolution in human resources, resources that in some part have altered, and in far greater part can alter, the material conditions of man's life.

Science, for all the brilliance of its contemporary development, for all the ingenuity of its technical invention, is still continuous with man's long history of rational life, of which it is a part; it is still the inheritor of the hope, so deeply founded in both Eastern and Western cultures, that, by reason and by open-minded efforts at understanding, man could not only enrich his life but better cope with the decisions that it fell to him to make. Those who are active, however modestly, in the work of science tend to feel themselves the inheritors of this tradition and of this hope. They see how vastly science, and the technology that is both its instrument and its consequence, have increased the range and difficulty and subtlety of the occasions on which decisions are required of men; they note how characteristic it is of these decisions that in one way or another they rest not with one man but with some community of men. They ask, as in all humility they must ask, whether in their own successful experience there may be any elements that could be helpful in the wider issues that confront mankind.

This is a wholesome question in the contemporary world: a world threatened with wars of vast destruction and countless particular cruelties, a world divided not only as to what constitutes truth but as to how truth can at all be established, a world overripe for the fruits of science yet in great areas destroying the essential conditions of its existence.

THE DAY is long past—if indeed it ever existed except in legend—when the whole of science was the expert province of any one man. These 10 reports are not addressed to the expert but to the interested layman. They attempt to tell, and I think for the most part with great success, of the high spots in the story of the last 50 years. There are of course important points of specific common interest between the sciences, where progress in one has made possible spectacular advance in another: so it has been with physics and astronomy, with biochemistry and physiology; so it will surely be with chemistry and genetics. The past decades have been marked by many such examples of the mutual fructification between sciences, and all signs point to its growth in the years ahead. In this happy sense a reader can discern evidences of the unity of science as he follows the reports here published.

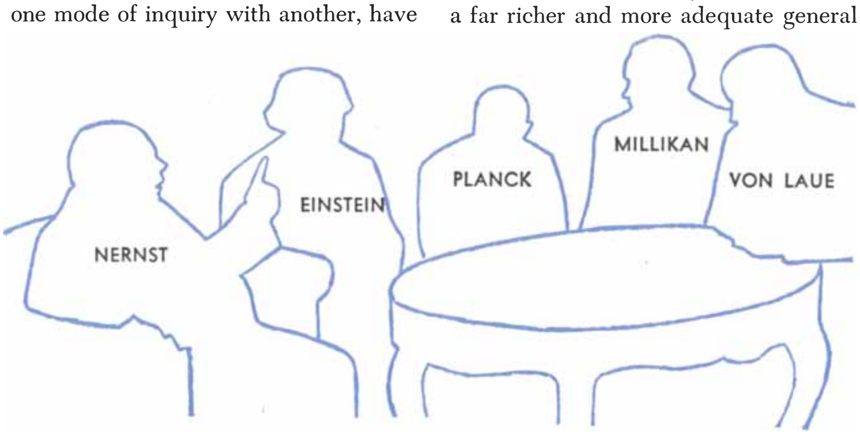
But even more striking is another almost opposite impression: that of an extraordinary diversification and specialization of the several sciences. They differ from one another, and their various parts differ from one another, by experimental techniques, by emphasis, by the kind of regularities that research reveals, by almost everything that might be codified as method. Most scientists will follow with pleasure what is written in the reports; few will fail to find something in them that is new, or newly clear; but none, I think, will recognize in himself any real technical competence, any basis for sound critical judgment, or for new discovery or new understanding, except in a very, very limited part of the broad field of contemporary science. This science is a land of extreme specialization and wonderful diversity, where the advances made by any one man rest, and necessarily rest, on the work of countless others, who characteristically have used techniques and ideas quite different from his own. This is a cooperative enterprise resting on specialization; its unity is based on the fullest exploitation and encouragement of diversity. The diversity is an appropriate reflection of the many-sidedness of our experience of nature; the unity, which we like to call the unity of nature, is in the first instance a result of the systematic application of the conviction that contradiction is a sign of error, a beginning for inquiry. The varied researches which in their totality make up contemporary science can never inhibit but only fructify one another: where their outcome appears to conflict, that conflict gives rise to new inquiry and the discovery of new truth.

Thus the order that characterizes the relations of one part of science with another is not primarily an hierarchal order. It is true that there have been attempts to sketch out possible hierarchies, designating, let us say, physics as more abstract than biology, or astronomy as more quantitative than anthropology. But it is doubtful whether such schemes have contributed much either to the growth of science or to its general understanding; certainly they do not describe at all the benign and tolerant symbiosis in which the sciences have flourished and nourished one another. Tolerance, open-mindedness and confidence in the resolution of conflict by further inquiry—these constitute the liberalism of the sciences in their relations with one another. These relations are rooted in many things, but not least in mutual respect and in a total, a deliberate candor.

OUR VIEWS on the relations of one set of researches with another, of one mode of inquiry with another, have been refined and deepened in an important way by the discoveries of the past half-century in one branch of science: atomic physics. It is probably true that in the past centuries physics led to the most nearly monistic, the least dialectical, the most hierarchal view of the order of nature. Yet it is just here that we have been most sharply taught by experience of the inadequacy of such syntheses. The discoveries in physics, which are described briefly in Born's article, revealed the inapplicability of causal, Newtonian physics to problems of individual atomic systems; they uncovered the universal duality between corpuscular and undulatory descriptions of atomic systems. Codified in the powerful formalism of the quantum mechanics, they were in the first instance given an acceptable epistemological formulation in Bohr's principle of complementarity. The basic finding was that in the atomic world it is not possible to describe the atomic system under investigation, in abstraction from the apparatus used for the investigation, by a single, unique, objective model. Rather a variety of models, each corresponding to a possible experimental arrangement and all required for a complete description of possible physical experience, stand in a complementary relation to one another, in that the actual realization of any one model excludes the realization of others, yet each is a necessary part of the complete description of experience in the atomic world.

It is of course not yet fully clear how characteristically or how frequently we shall meet instances of quite close analogy to the complementarity of atomic physics in other fields, above all in the study of biological, psychological and cultural problems. Yet it is clear, as has repeatedly been stressed by Bohr himself, that the discovery of complementarity has provided us with a far wider and more sophisticated framework for the synthesis of varieties of scientific experience. It has refined and extended the pluralism natural to science, and added new elements of subtlety to the idea of dialectic. Indeed, it seems to offer a far richer and more adequate general point of view for the comprehension of human experience than the misleadingly rigid and unitary philosophies that flowed so naturally from the experiences of Newtonian mechanics. It has also tended of course to emphasize the elements of analogy between the scientific tradition and the great traditions of Oriental philosophy, of Lao-tse and of Buddha—a circumstance which may hold some promise at this time, when understanding between diverse cultures seems more imperative than ever before.

The candor, the openness, of science is too well known to need elaborate emphasis. Yet it is basic. The most elementary student is taught to preserve and make available direct records of his experience. However obscure the findings or recondite the subject, the procedures of scientific investigation must be straightforwardly describable and communicable, so that work may be repeated at will. The mutual respect and the tolerance which ought to prevail, and so largely do prevail, in the sciences, rest in overwhelming measure on this complete accessibility. It is through this



FIVE NOBEL PRIZE WINNERS in physics met at Berlin-Zehlendorf in 1931. Walter Nernst had stated the third law of thermodynamics. Albert Einstein was the author of the special and general theories of relativity.

that a scientist, no matter how narrow his field of specialization, comes to be an equal member in a community: not because he shares the experience of all other workers or even a substantial part of it, but because no barriers have been raised and all efforts have been addressed to reducing the barriers to a minimum. Few of us can forget the delight of entering a new field of inquiry that appeared relevant at one time or another to our own work but had hitherto been unknown to us.

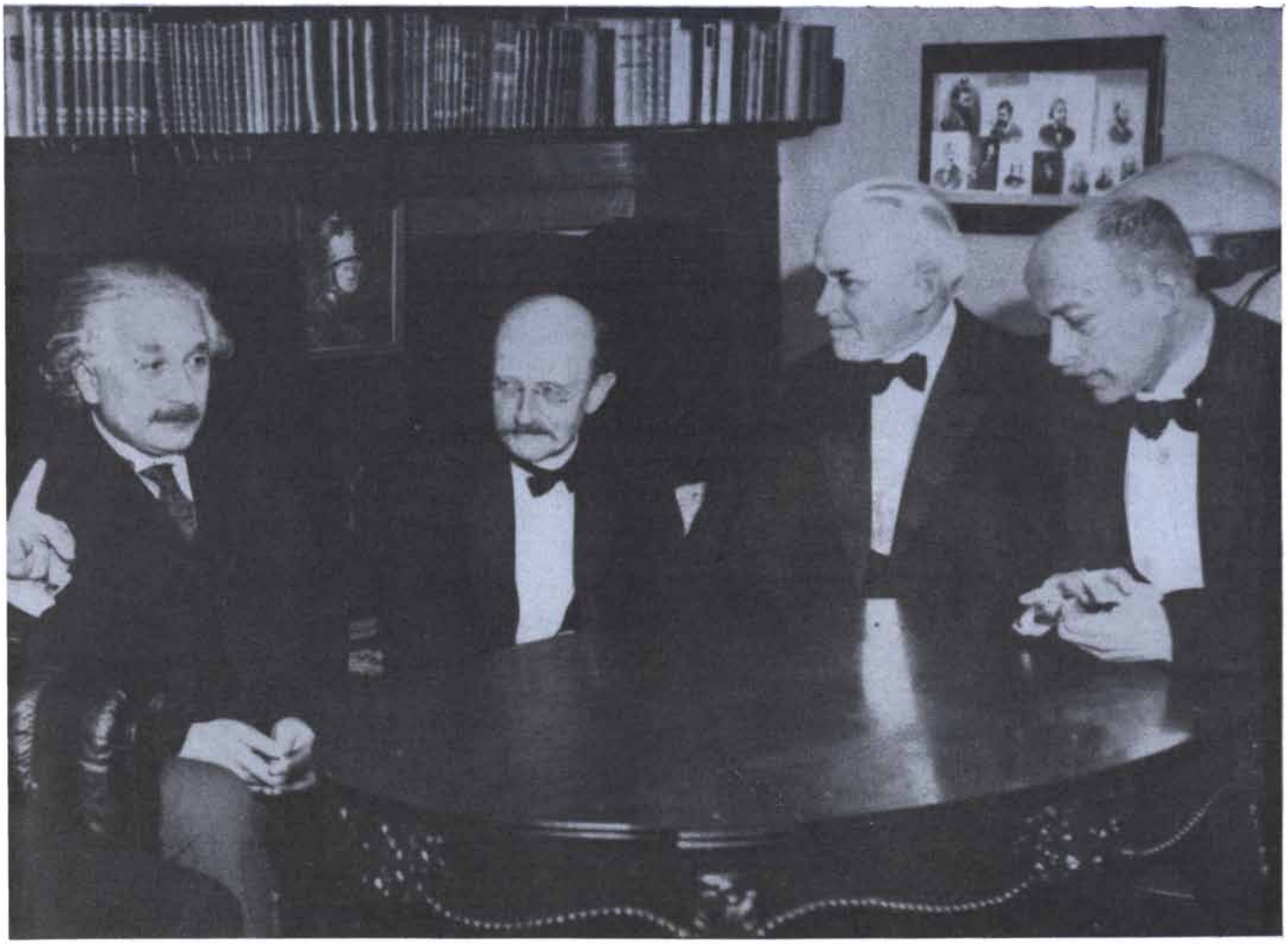
NO DOUBT there are elements of overidealization in this sketch of the relation of the individual scientist to his scientific community. Honor, prerogative and worldly pomp do sometimes, briefly and almost trivially, color and infect that relation. Yet there are few human institutions in which cooperation is more fruitful or the freedom of the individual conscience and taste more complete, where mutual respect makes for so great a harmony between the flourishing of the community and the liberation of the individual man.

This harmony, even in science itself, is being destroyed or threatened in vast areas of the world today. Terror, orthodoxy, recantation, hierarchy, secrecy—these words are full of grim omens for science and for liberty. A society which as a matter of principle invokes the measures for which these words stand betrays, whatever its protestations, science and the tradition that has nourished it. A society which invokes these measures (in the name of man's welfare, in fear or in folly) is in danger of death.

Increasingly, in these days of growing crisis, men have talked with earnest desperation of the application of scientific method to new areas, to problems of man's behavior and to human society. None of us knows or can foresee what progress individual genius and common effort may make possible in our understanding of these problems in the decades to come. Yet if the history of other sciences is a good guide, progress will come in only fitful and wayward response to man's needs, and will wait upon his insight, his patience and his invention. From this modest view, I think, neither Cantril nor Kroeber would dissent.

Yet science itself in its nature is, largely has been and in our hopes necessarily must be, world-wide. The need for the practical fruits of science is world-wide, as universal as man's striving to improve his lot on earth. The community of science is a limited but worthy prototype for that tolerant, open, open-minded community of men which alone can maintain the progress of civilization, which alone can contribute in these critical times to fulfilling the aspirations of mankind.

J. R. Oppenheimer, theoretical physicist, is perhaps best known as the wartime director of the Los Alamos Scientific Laboratory. Before the war he had been professor of physics at the University of California and the California Institute of Technology. He is presently chairman of the General Advisory Committee of the Atomic Energy Commission and director of the Institute for Advanced Study.



Max Planck had originated the quantum theory. Robert A. Millikan had measured the charge of the electron. **Max von Laue had suggested the application of X-ray diffraction to show the arrangement of atoms in crystals.**